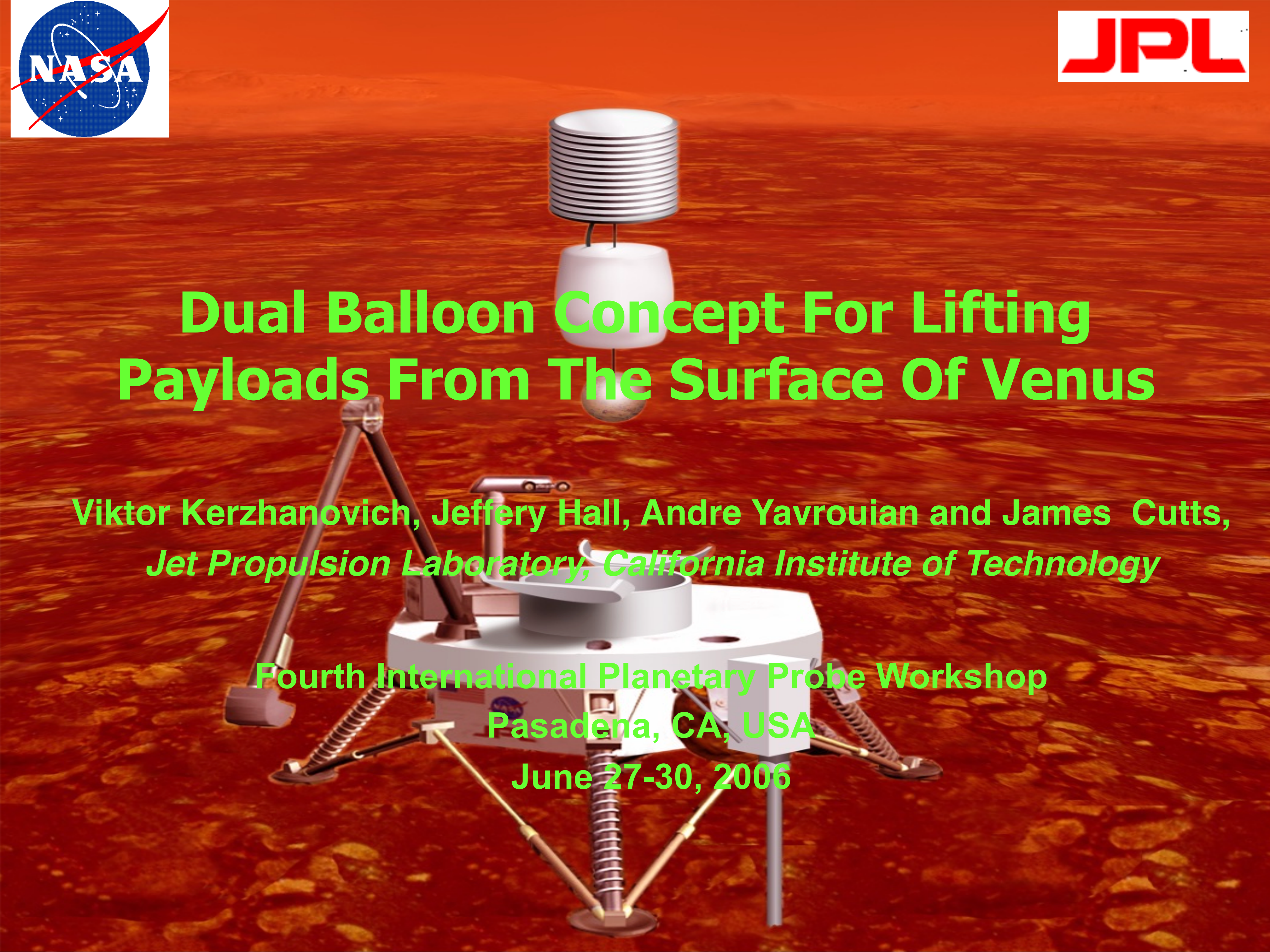

Dual Balloon Concept For Lifting Payloads From The Surface Of Venus

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BACKGROUND

- **Why Venus?**
  - **Detailed knowledge of environment and evolution of Venus is vital to prevent Earth to become Venus twin**
  - **Fundamental questions about surface and atmosphere composition unanswered**
  - **Global superrotation of the atmosphere is still enigma**

- **Last in situ mission was 20 years ago – two VEGA probes and two balloons**

- **NASA/NRC guiding documents and Venus "White paper" named three highly-ranked missions requiring balloons**

FUTURE VENUS MISSIONS NEED BALLOONS

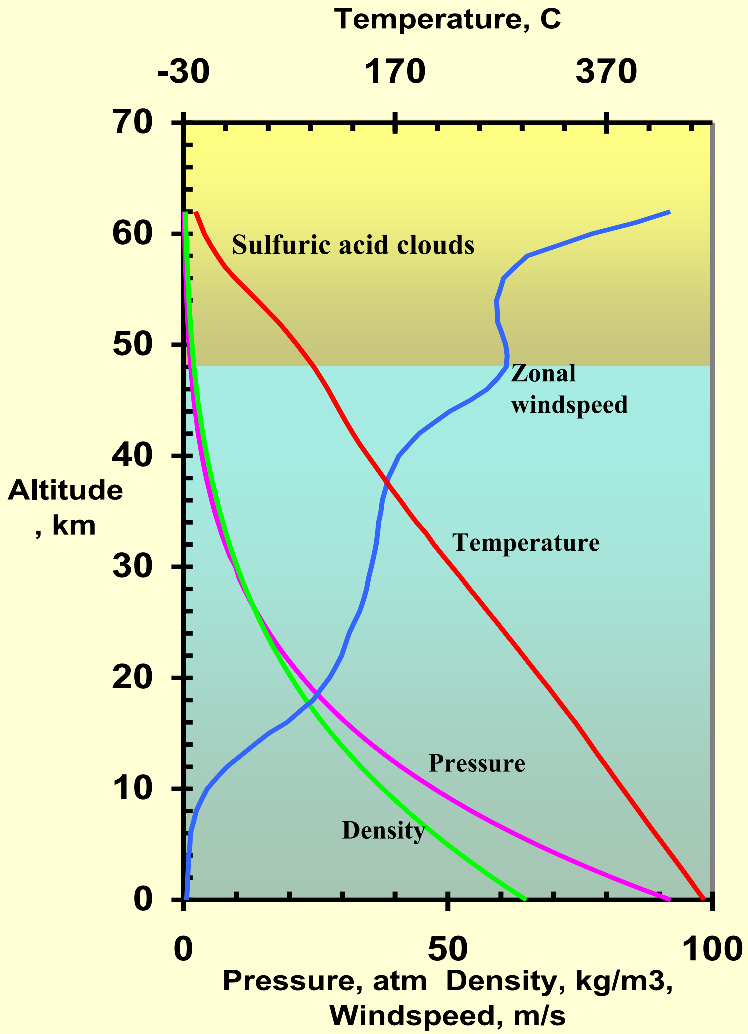
- Venus In-Situ Explorer (VISE)
  - Probe to land on the surface
  - Surface sample acquisition
  - Balloon to lift 50-100 kg ascent module with sample and instruments at benign environment in the atmosphere (53-55 km) for detailed sample analysis

- Venus Surface Sample Return (VESSR)
  - Probe and return rocket (Venus Ascent Vehicle – VAV) to land on the surface
  - Surface sample acquisition
  - Balloon to lift 500-600 kg VAV with sample canister upper atmosphere (58-65 km) for launch to Venus orbit and then to Earth

- Venus Atmospheric Dynamics Explorer
  - Tracking of multiple balloons at altitudes from near surface to 60-65 km
  - Tracking cloud motions from orbiter (Venus Express is doing now)

VENUS ENVIRONMENT AND BALLOONING

- Wide range of balloon-related parameters
  - Autoclave at the surface: temperature 463 C, pressure 92 bars, density 64 kg/m^3, windspeed <1.5 m/s, clear atmosphere
  - Benign Los Angeles smog with category 5 hurricane winds at 55 km: temperature 30 C, pressure 0.53 bar, density 0.92 kg/m^3, concentrated sulfuric acid haze, windspeed 70 m/s
  - Earth stratosphere above 67 km: temperatures <-40C, pressure <70 mbar, density <0.15 kg/m^3



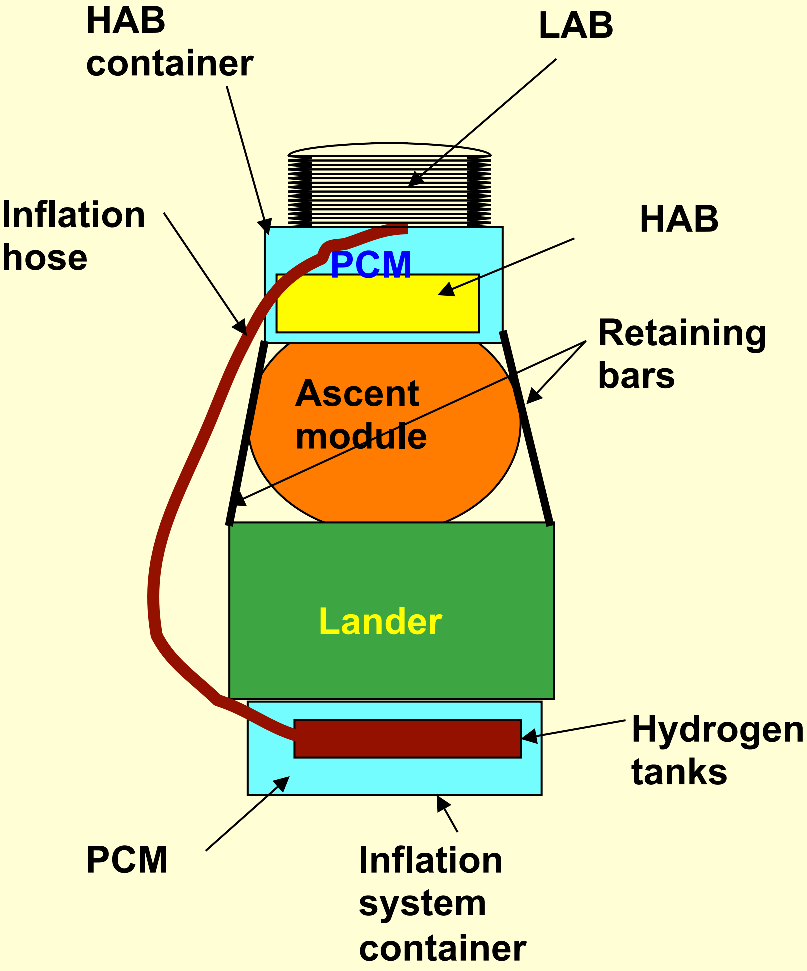
VENUS CARGOLIFTING BALLOON

- Main requirements
  - Tolerate 460 C surface temperature for several hours
  - Tolerate concentrated sulfuric acid at upper atmosphere for 1-24 hours
  - Lift payloads from 50 to 600 kg to ~ 60 km altitude (136 times balloon volume increase)
  - Packing in the aeroshell
  - Autonomous surface lunch

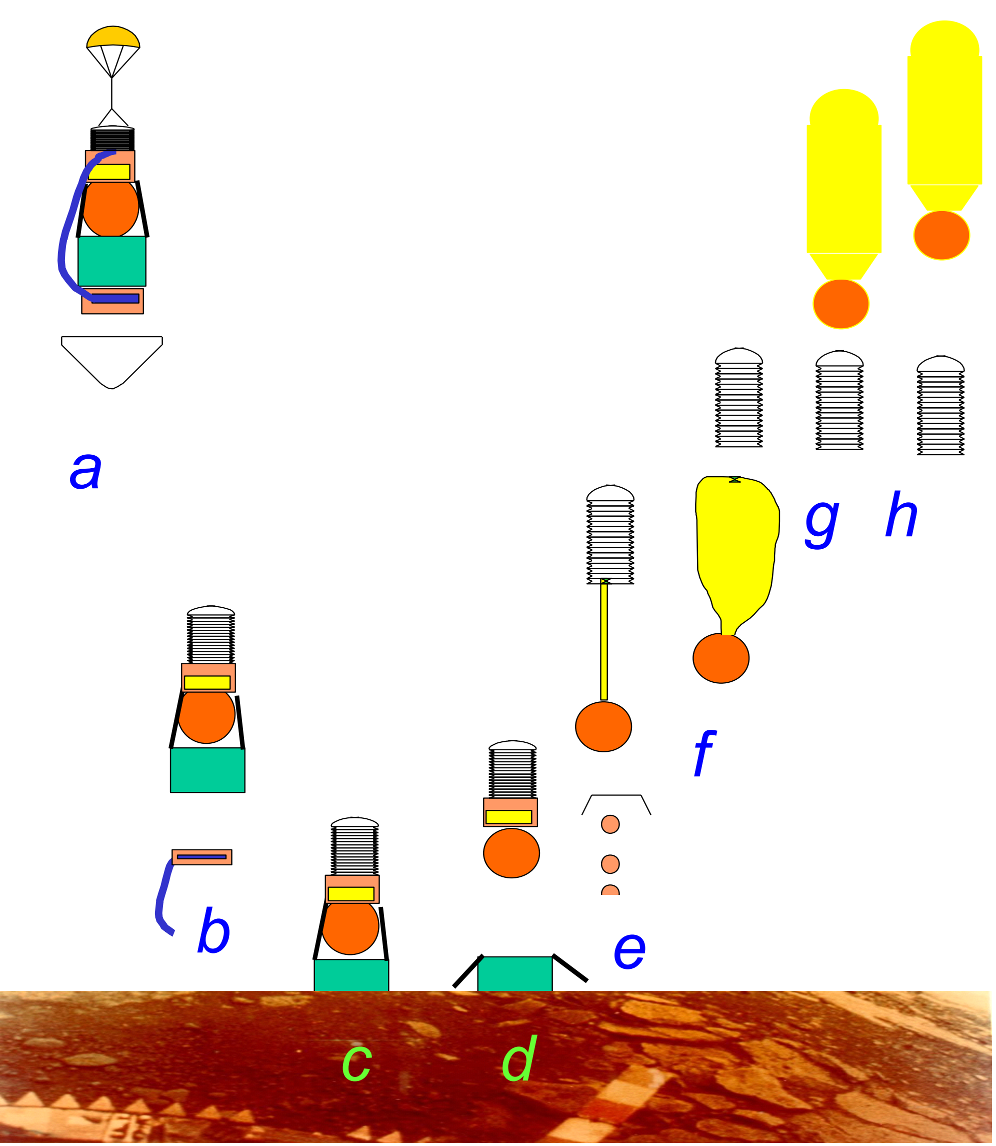
- Single balloon: no appropriate material so far
  - Teflon film melts at surface temperatures and highly permeable
  - PBO film
    - Does not tolerate sulfuric acid, need coating
    - Still in experimental phase, future unclear
  - Kapton FN film (Kapton co-extruded with Teflon)
    - Brittle above 400 C
    - Teflon sticky at high temperatures
  - Metal foils: no tear resistance, too fragile

DUAL-BALLOON APPROACH

- Divide balloon system in two parts optimized for low-altitude and high-altitude operations
- Low-altitude balloon LAB has small volume, expands <2.5 times and might be built of robust high-temperature material
- High-altitude balloon HAB operates at temperatures <350 C, expands >50 times and has to built of light-weight polymer film
- HAB kept at moderate temperatures inside thermally insulated enclosure until deployment
- LAB – metal bellows



DUAL-BALLOON MISSION CONCEPT



a – h=140-2 km: entry, aeroshell separation, descent to low atmosphere; PCM thermal control of hydrogen tanks and HAB

b - h~2 km: open valve to inflate LAB, release tanks, LAB filled to ~1/3 of volume

c – h=0 km: landing; LAB buoyancy stabilizes attitude and reduces velocity; surface sampling and sample transfer

d – h=0 km: release retaining bars, launch from surface, leave lander

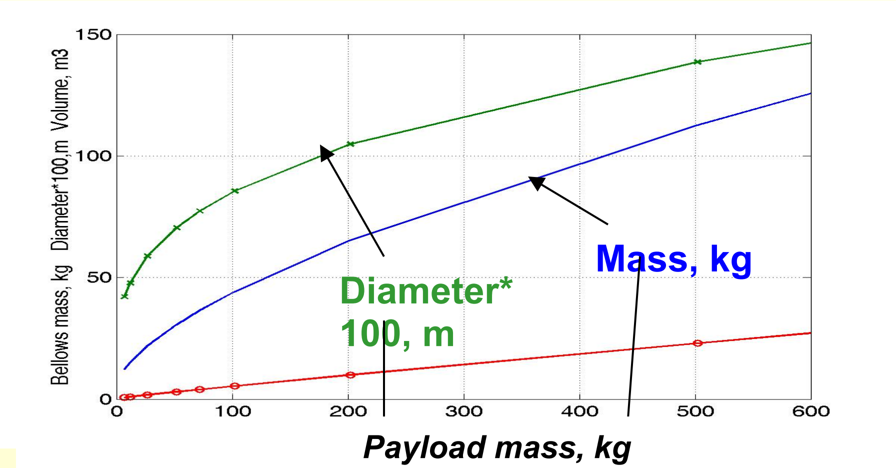
e – h=10-20 km: crossover altitude, LAB expanded to maximum volume; HAB deployment, release HAB container, open valve between HAB and LAB; gas expanding from LAB begins to fill HAB

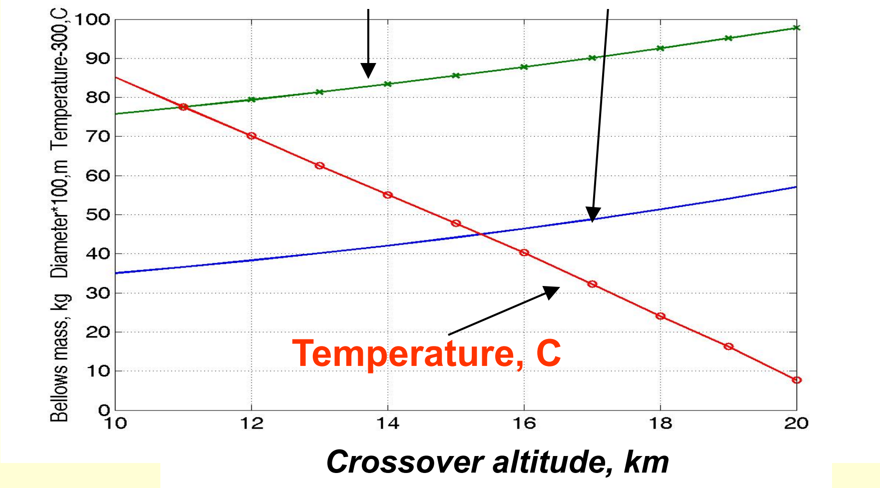
f – h=30-35 km: end of HAB inflation and LAB separation

g – h~30~60 km: HAB ascent to cruise altitude
h – h=53-60 km HAB at cruise altitude, analyze sample, launch VAV

METAL BELLOWS AS LOW-ALTITUDE BALLOON

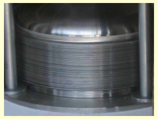
- Existing technology at Gardner Bellows Corp
- Tested bellows 0.35 m diameter 70 convolutions, stainless steel, 7-mil thickness
- Stored length 0.19 m, maximum expansion 2.16 m
- Passed +460 C test, no damages or leakage





•Critical design factors

- Payload mass
- Crossover altitude



ΔP= -84 mB

ΔP= 114 mB

DP= 630 mB after exposure to +460 C

Need 0.8 m diameter 46 kg bellows to lift 100 kg payload to crossover altitude 15 km

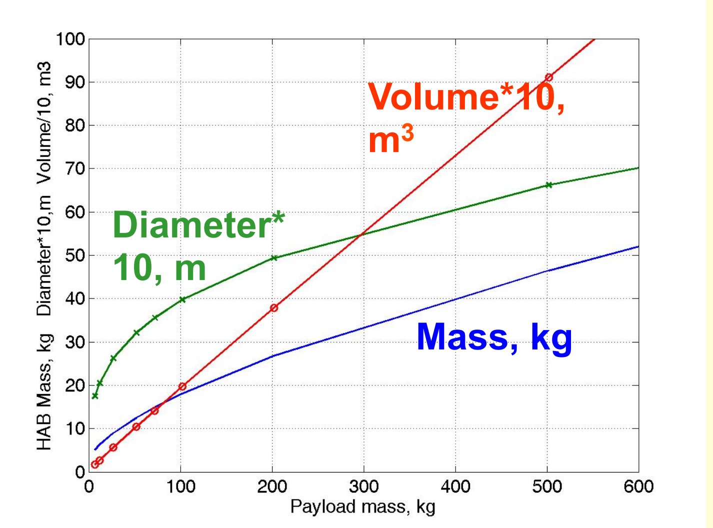
HIGH-ALTITUDE BALLOON

- **Material**
  - Kapton FN film – Kapton film co-extruded with Teflon FEP
  - No degradation or brittleness below 400 C
  - Sulfuric acid tolerant (Teflon outside)

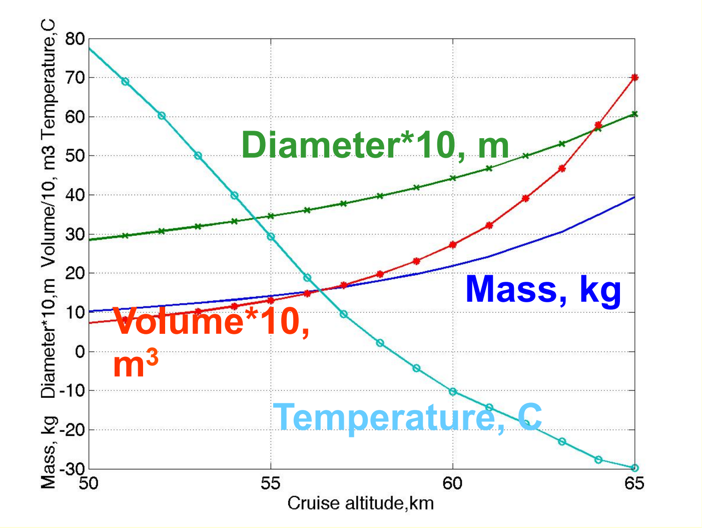
- **Design**
  - Zero-pressure
  - Cylinder with load tapes

- **Deployment: aerial at crossover altitude**

- **Critical design factors**
  - Payload mass
  - Ceiling altitude
  - Crossover altitude temperature



Payload mass, kg



Crossover altitude, km

DUAL-BALLOON SYSTEM MODEL

- Model simulates the dual-balloon system trajectory and thermal state in all phases from beginning of descent to ascent to the cruise altitude; all system elements and all separations included

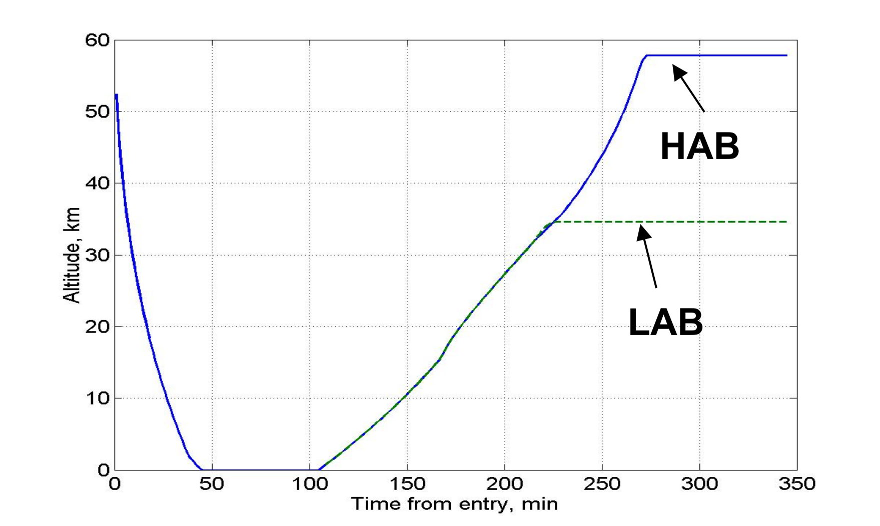
- Trajectory and thermal
  - Terminal velocity equation for vertical motion
  - Aerodynamic drag, gravity and buoyancy forces
  - Horizontal velocity equal to wind velocity at appropriate altitude

- Thermal
  - Vented insulation with thermal conductivity =thermal conductivity of atmosphere * 1.5
  - PCM in solid phase at beginning, then melting and heating further

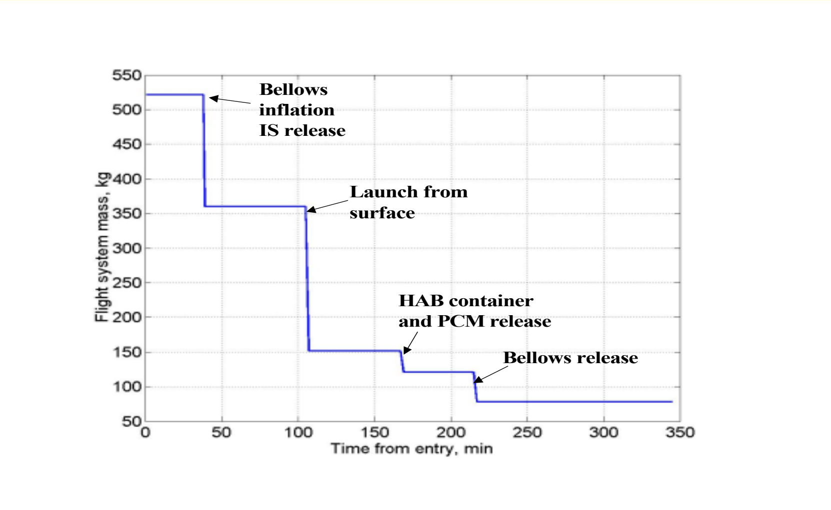
EXAMPLE OF DUAL-SYSTEM SIMULATION

- Ascent module mass 70 kg
- Crossover altitude 15 km
- HAB ceiling 58 km
- Lander mass 70 kg
- Bellows: diameter 0.91 m, maximum volume 6.55 m^3, mass 43 kg
- HAB: cylindrical balloon, 3.4 m diameter, volume 123 m^3, mass 8.2 kg
- Buoyant gas – hydrogen, 8,4 kg
- PCM - water ice / water: 22.7 kg for HAB, 54 kg for tanks protection
- Probe mass at descent after aeroshell release 530 kg
- System mass at launch from surface 160 kg
- Floating mass at ceiling 86 kg
- Time on surface 1 h

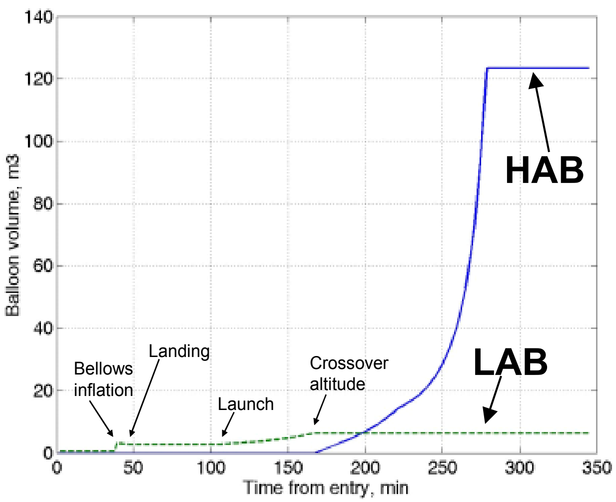
SIMULATION RESULTS



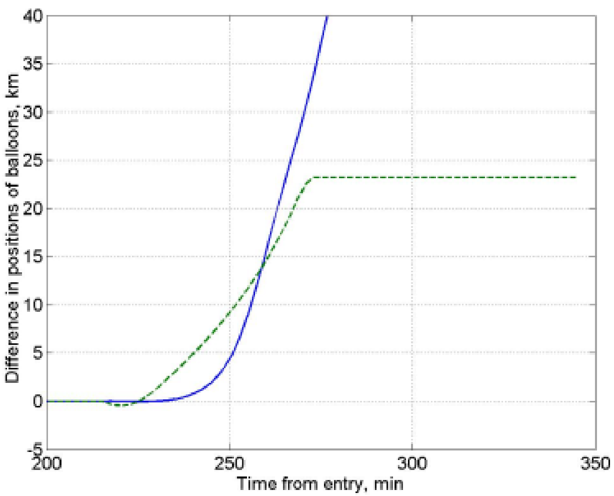
Altitude history



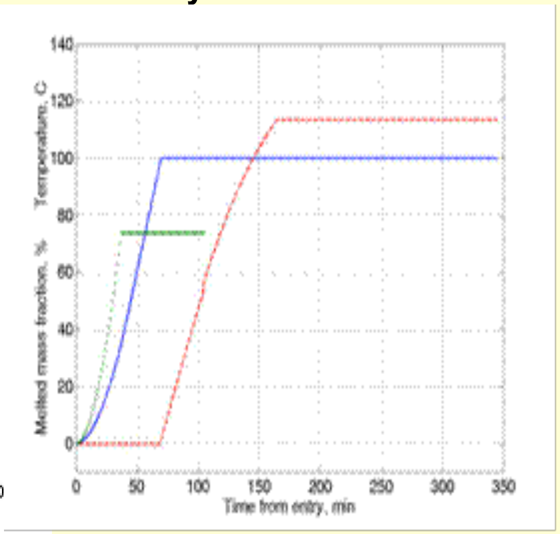
System mass history



Inflated volume of balloons



Horizontal and vertical separation between HAB and LAB after LAB release



Melted mass fraction and PCM temperature

SUMMARY

- The dual-balloon system is the first real approach for high temperature Venus balloon missions like VISE and VESSR
- In spite of looking futuristic, only existing materials and technology used; no showstoppers so far
- Developed model can be used for trade studies
- Smaller scale precursor mission will validate the concept
- By itself, the metal bellows can fly in any altitude from near the surface to 15-20 km while Kapton FN film balloons can fly from 15-20 to 60 km. Addition of superpressure balloons and polyethylene zero-pressure balloons will open all range of altitudes from surface to 75-80 km for balloon missions